



Full Vehicle Simulation for Parallel Hybrid Vehicles

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Outline

Parallel Hybrid Simulation

- **Background**
- **Description of Full Vehicle Simulation**
- **Using the Simulation**
- **Hybrid Battery Sizing Sample Study**
 - **Problem Definition**
 - **Baseline Vehicle Results**
 - **Optimization Results**
- **Conclusion**

Background

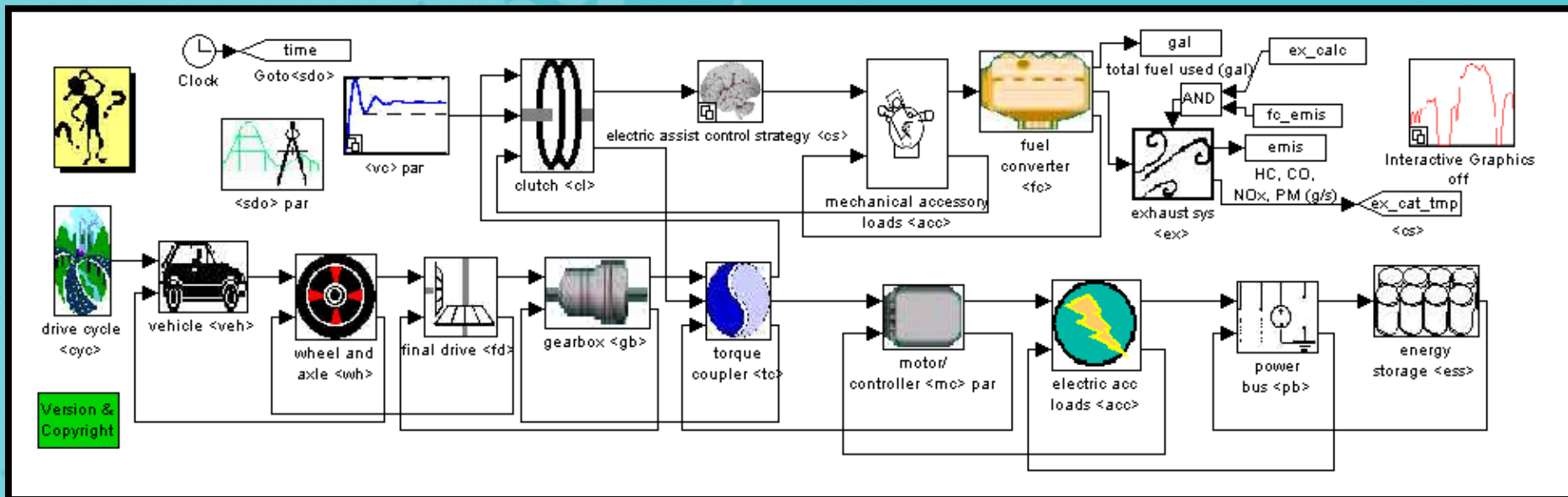
- **Goal: Parallel hybrid vehicle simulation**
 - Detailed electrical models
 - Full vehicle system context
- **Approach: Co-simulate detailed Saber electric component models in the full vehicle system context of ADVISOR**
 - Saber is often chosen for detailed electric component modeling
 - ADVISOR (ADvanced Vehicle SimulatOR), based in MATLAB/Simulink, is often chosen for modeling full vehicle systems

Outline

Parallel Hybrid Simulation

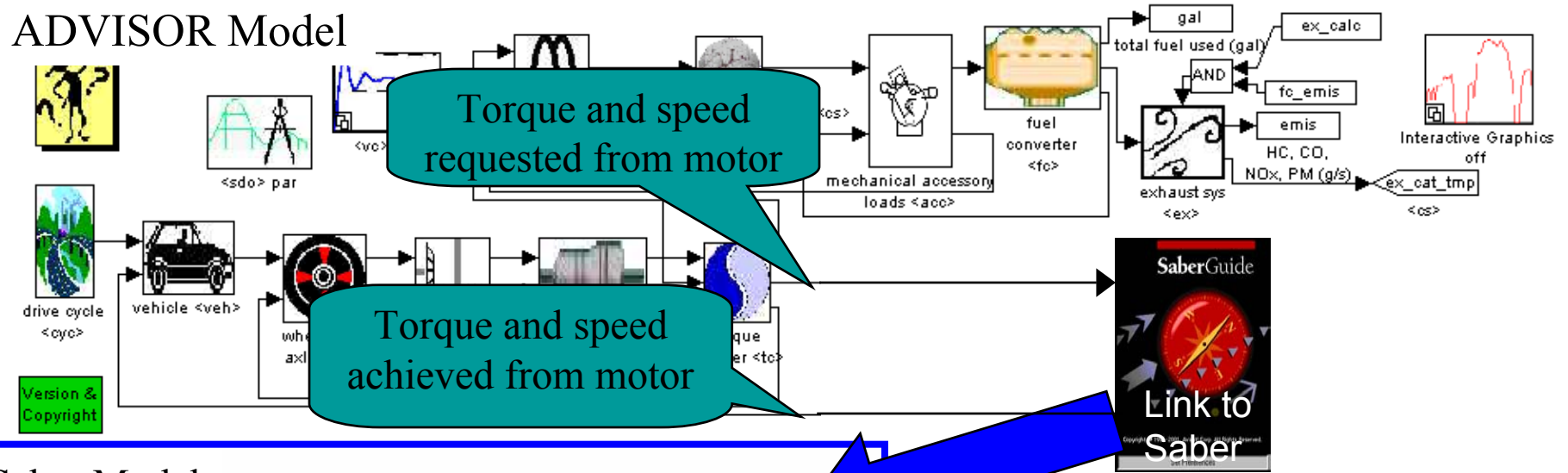
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- **ADVISOR models**
 - **Electrical solutions based upon power flow, not circuit equations**

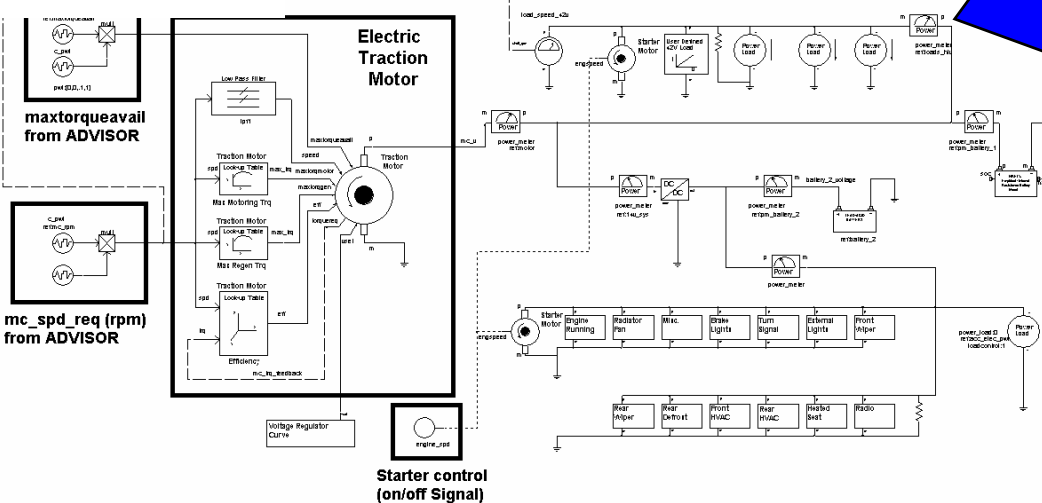


Description of Full Vehicle Simulation

ADVISOR Model



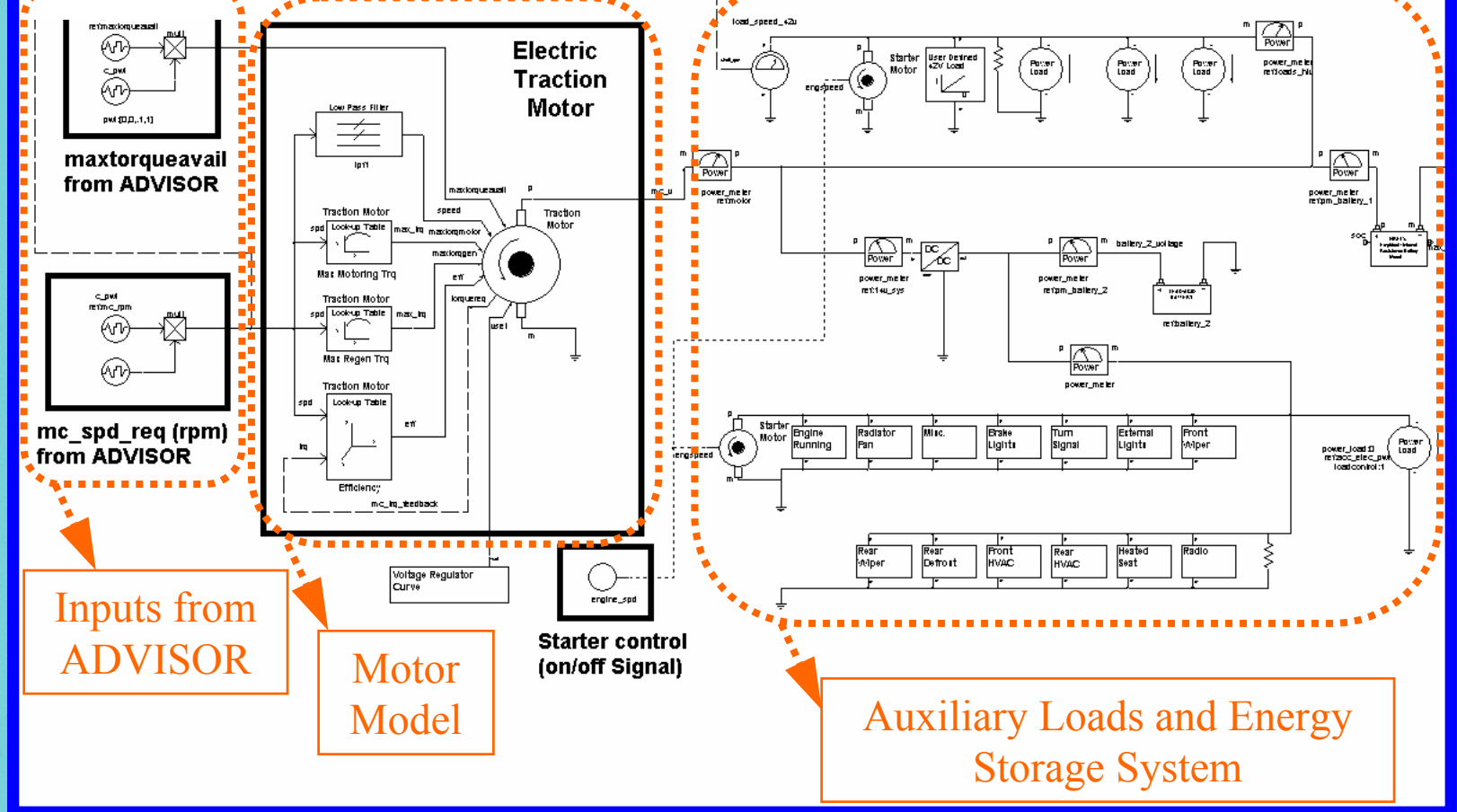
Saber Model



- Replace ADVISOR electric models with more detailed Saber models

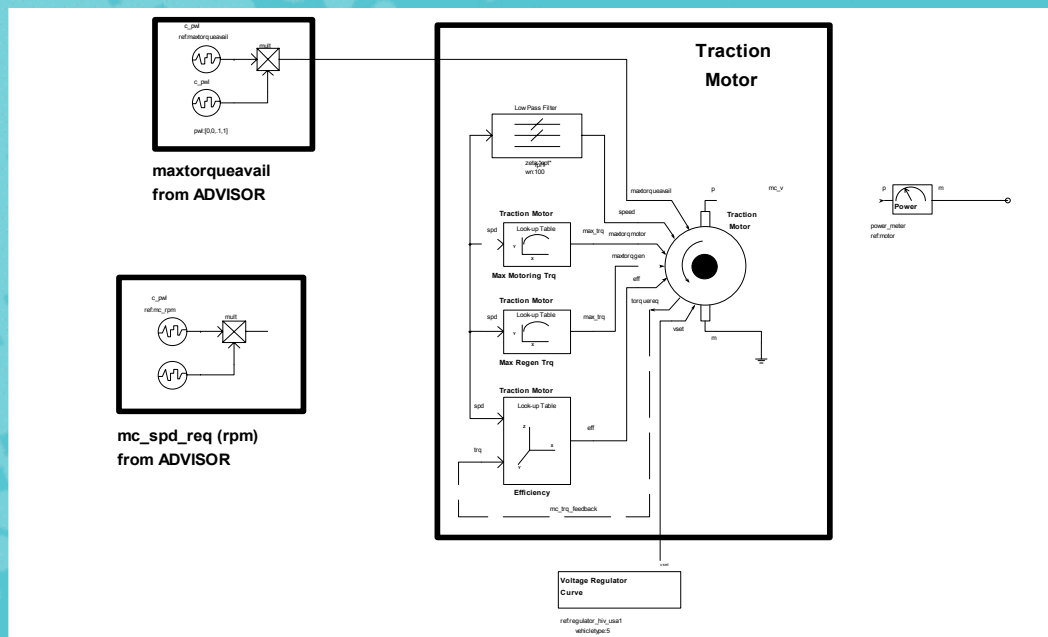
Description of Full Vehicle Simulation

Saber Model

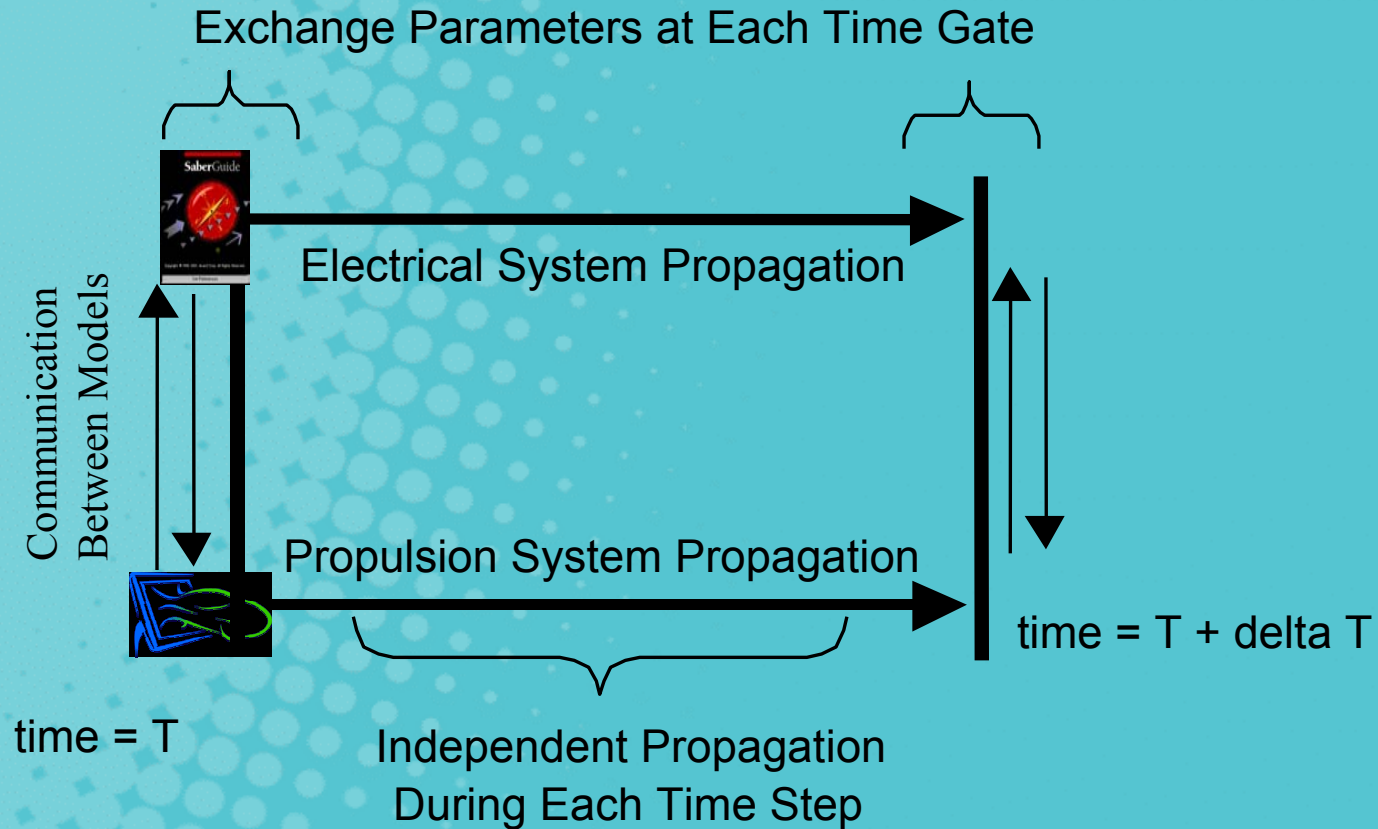


Description of Full Vehicle Simulation

- **Traction Motor Model for Hybrids**
 - Driven by lookup table, permitting empirical replications of hardware performance
 - Calibrates from the same m-file used by ADVISOR battery models



Description of Full Vehicle Simulation



Outline

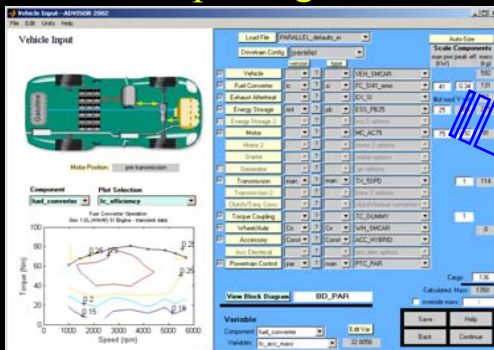
Parallel Hybrid Simulation

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Using the Simulation

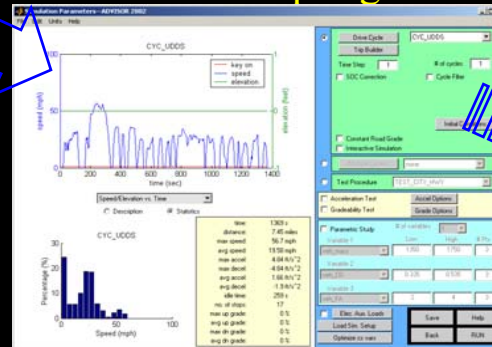
- ADVISOR is Simulink model based. The model, however, runs in the background.
- Three main figures sit on top of the model to feed it data and receive results.

Vehicle Input Figure



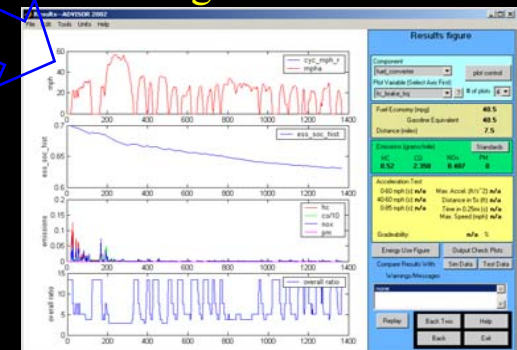
- ◆ Load Saber co-simulation model parameters
- ◆ Swap to the ADVISOR co-simulation model

Simulation Setup Figure



- ◆ Setup drive cycle
- ◆ Choose Auxiliary Loads

Results Figure

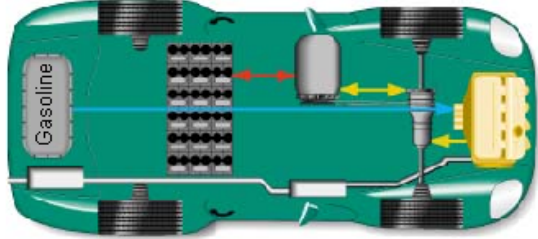


- ◆ View ADVISOR Results
- ◆ View Saber Results

Using the Simulation Vehicle Input Figure

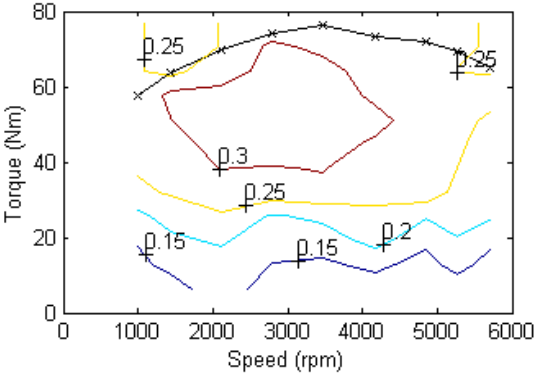
Vehicle Input--ADVISOR 2003beta
File Edit Units Help

Vehicle Input



Component **Plot Selection**
fuel_converter fc_efficiency

Fuel Converter Operation
Geo 1.0L (41kW) SI Engine - transient data



Vehicle Input Parameters:

Component	Version	Type	Value	Scale Components
Vehicle	?	VEH_SMCAR		max pwr (kW): 592, peak eff: 0.34, mass (kg): 125
Fuel Converter	ic	si	FC_SI41_emis	
Exhaust Aftertreat		EX_SI		#of mod V nom: 10
Energy Storage	rint	pb	ESS_PB25	19, 234, 209
Energy Storage 2	saber	pb	ESS2_PB54_14V_saber	5, 12, 19
Motor		MC_AC75		56, 0.92, 68
Motor 2		motor 2 options		
Starter		starter options		
Generator		gc options		
Transmission	man	man	TX_5SPD	1, 114
Transmission 2		trans 2 options		
Clutch/Torq. Conv.		clutch/torque converter c		
Torque Coupling		TC_DUMMY		1
Wheel/Axle	Crr	Crr	WH_SMCAR	0
Accessory	Var	Spd	ACC_SMALL_CAR_AC	
Acc Electrical		acc elec options		
Powertrain Control	sabP	man	PTC_PAR_Saber	

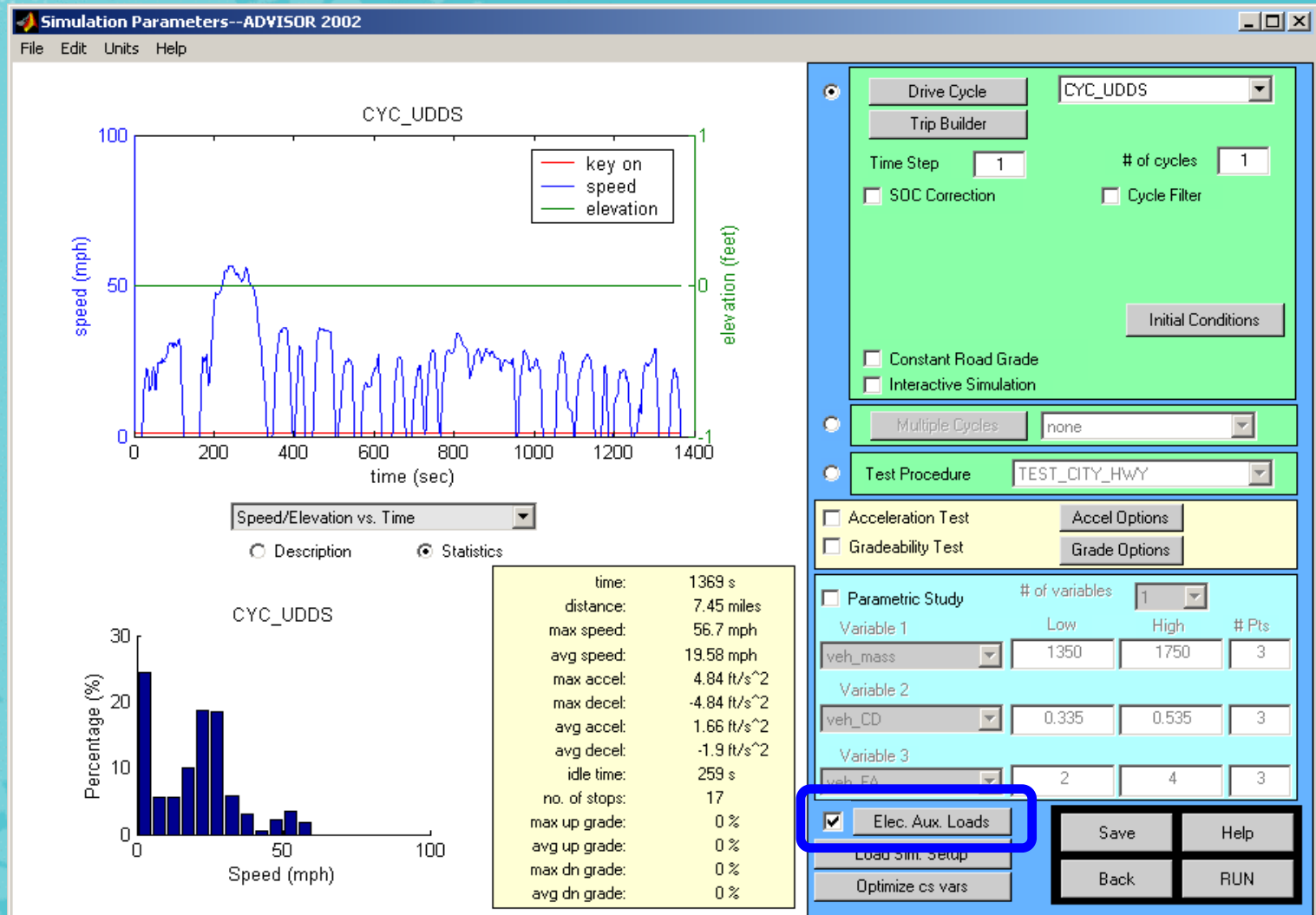
View Block Diagram ID_PAR_saber_cosin

Variable
Component: fuel_converter
Variables: fc_acc_mass 32.8056

Summary:
Cargo: 117
Calculated Mass: 1254
override mass: 1

Buttons: Save, Help, Back, Continue

Using the Simulation Simulation Setup Figure



Using the Simulation Auxiliary Loads Figure

City_summer_day_aux.mat

Saber Co-simulation
Selected Saber Co-simulation from Vehicle Input Screen. (Only available with conventional vehicle; must have Saber)

ADVISOR Alone
Allows use of programmable on/off control of constant power loads.

Additional Electric Loads

Load File: City_summer_day_aux.mat

Load	14V	Hi V	Type	Load Choice	On/Off Control	Power Use (Watts)	
						On	Cycle Ave.
<input type="checkbox"/> All Loads	<input checked="" type="radio"/>	<input type="radio"/>	Large_Car_1	Lowest	Control		
<input type="checkbox"/> Rear Defrost	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C		Control		
<input type="checkbox"/> Heated Seats	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C	High	Control		
<input checked="" type="checkbox"/> Radio	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C	One	Control	7	7
<input type="checkbox"/> Rear Wipers	<input checked="" type="radio"/>	<input type="radio"/>	SUV_3		Control		
<input type="checkbox"/> Front Wipers	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C		Control		
<input checked="" type="checkbox"/> Turn Signals	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C		Control	67	1
<input checked="" type="checkbox"/> Misc.	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C		Control	56	
<input checked="" type="checkbox"/> Front HVAC Fans	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C	AC_High	Control	296	296
<input type="checkbox"/> Rear HVAC Fans	<input checked="" type="radio"/>	<input type="radio"/>	Minivan_1	High_AC	Control		
<input checked="" type="checkbox"/> Engine	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C		Control	80	
<input checked="" type="checkbox"/> External Lights	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C	Day_Lights	Control	84	84
<input checked="" type="checkbox"/> Radiator Cooling Fan	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C	High	Control	367	367
<input checked="" type="checkbox"/> Brake Lights	<input checked="" type="radio"/>	<input type="radio"/>	Sub_Compact_C		Control	79	
<input checked="" type="checkbox"/> Starter	<input type="radio"/>	<input checked="" type="radio"/>	Default		Control	1000	
<input type="checkbox"/> Power Load 1	<input checked="" type="radio"/>	<input type="radio"/>	Catalyst_Heater		Control		
<input type="checkbox"/> Power Load 2	<input checked="" type="radio"/>	<input type="radio"/>	Oil_Pump		Control		
<input type="checkbox"/> Power Load 3	<input checked="" type="radio"/>	<input type="radio"/>	Water_Pump		Control		
<input type="checkbox"/> Current Load	<input checked="" type="radio"/>	<input type="radio"/>	Default		Control		
<input type="checkbox"/> Speed Load	<input checked="" type="radio"/>	<input type="radio"/>	ElectMagValvtrn		Control		
Total:						2036	

Existing Electric Load

acc_elec_pwr (constant load): 0 acc_elec_eff (efficiency): 1

Total 14V Current Load:

RearDefrost

Options: 1

Initial Conditions

Options: 1

High #Pts: 1750 3

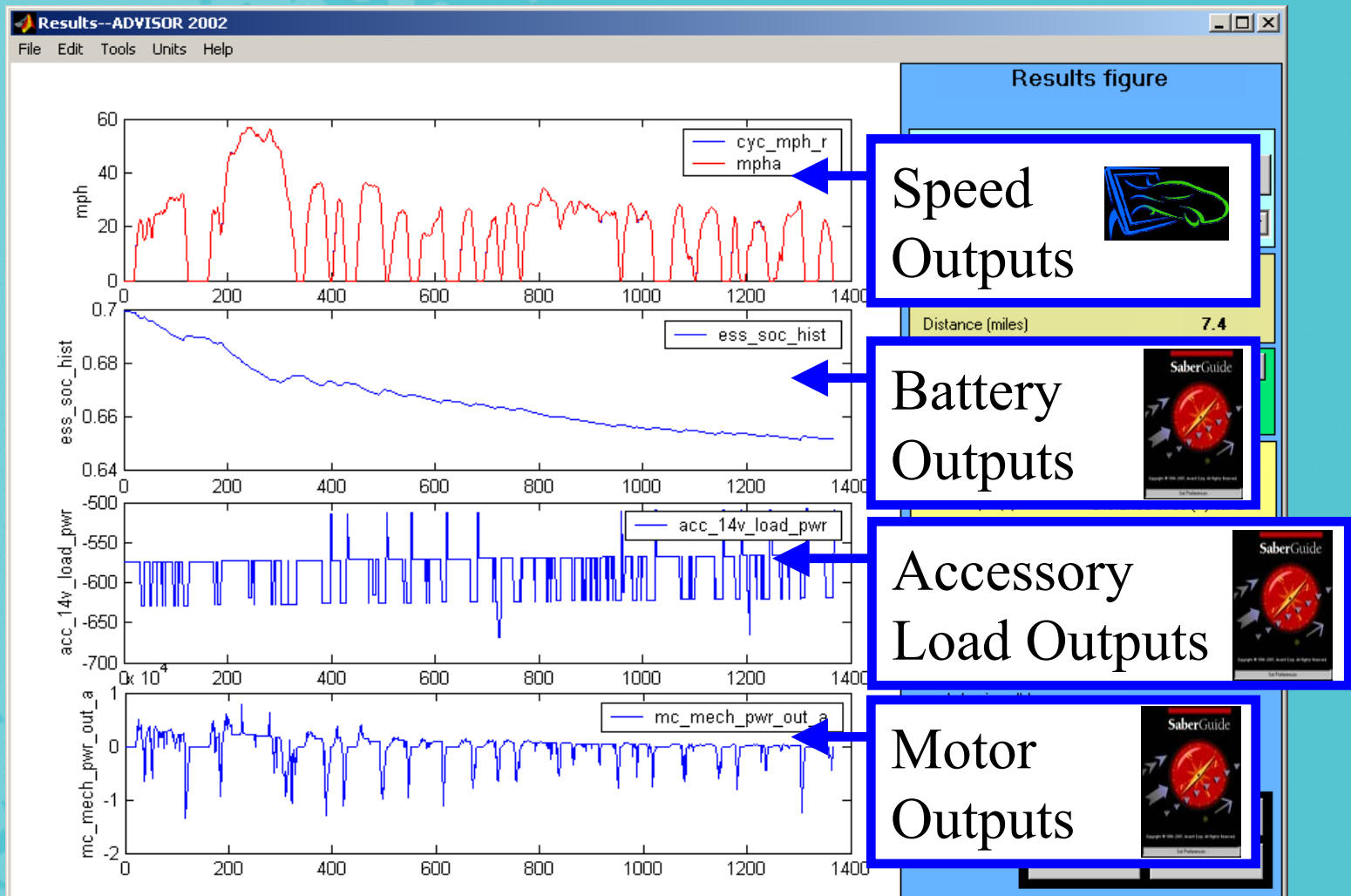
0.535 3

4 3

Help

RUN

Using the Simulation Results Figure



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Hybrid Battery Sizing Sample Study

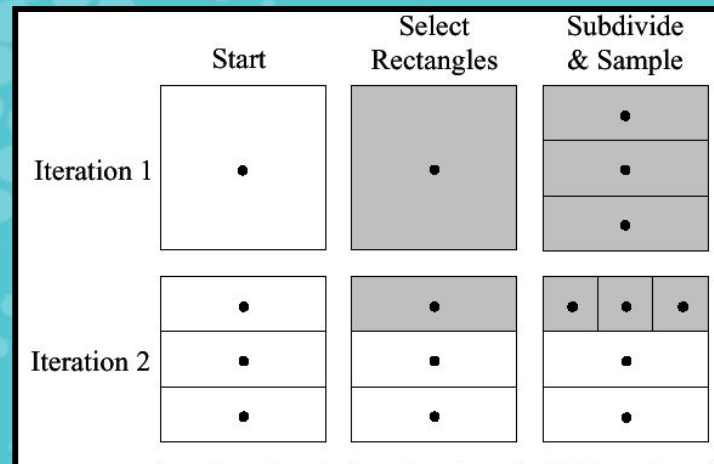
Problem Definition

- **Objective**
 - Maximize fuel economy over urban dynamometer driving schedule (UDDS)
- **Constraints**
 - Accelerate from 0 to 60 mph in 11 seconds
 - Stay within 2 mph of UDDS speed trace
- **Design variables**
 - Engine size
 - Nominal engine size: 41 kW
 - Engine scale limits: 16.4 kW – 61.5 kW
 - Motor size
 - Nominal motor size: 75 kW
 - Motor scale limits: 7.5 – 37.5 kW
 - Discrete Battery Capacity
 - 144 V NiMH
 - 45 Ah, 60 Ah, 90 Ah

Hybrid Battery Sizing Sample Study

Problem Definition

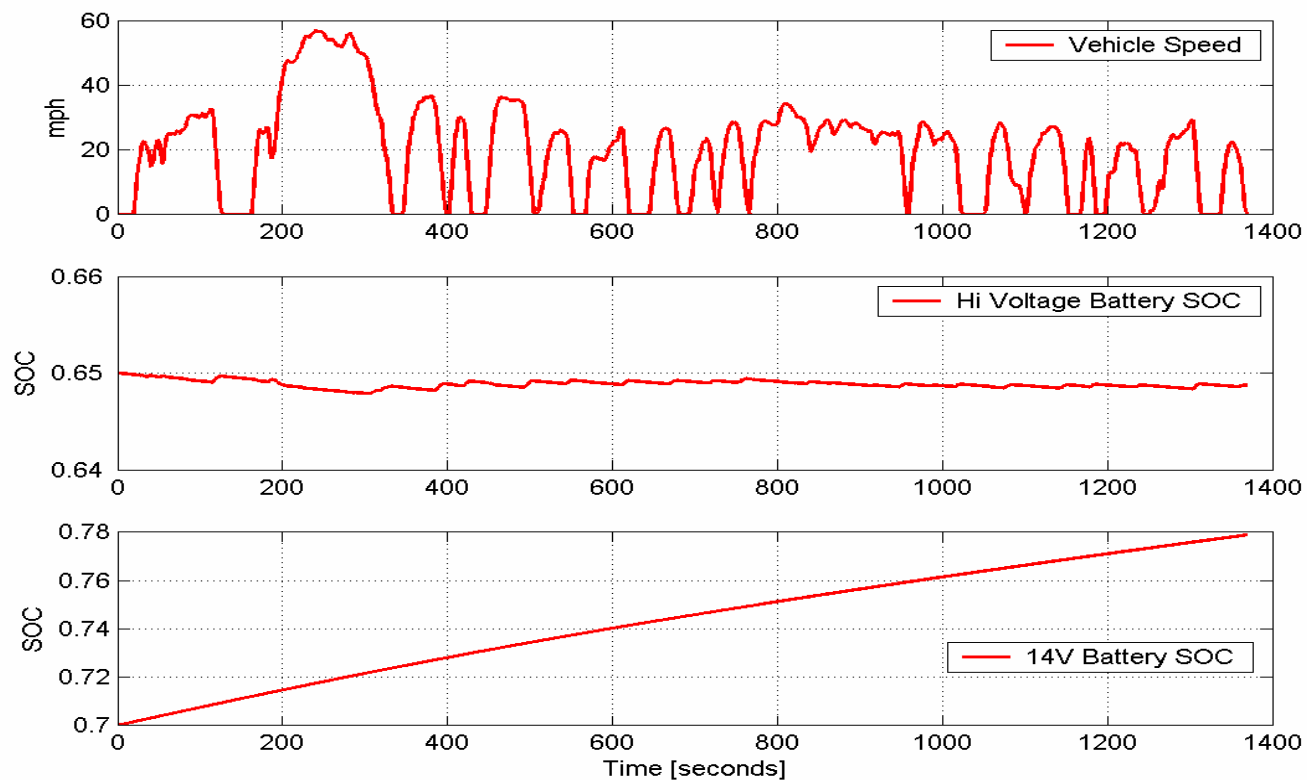
- **Simplifying assumptions**
 - Power assist parallel Saber co-simulation vehicle (small car)
 - Linear SOC balancing (computational efficiency)
 - DIRECT optimization routine



Hybrid Battery Sizing Sample Study

Baseline Vehicle Results

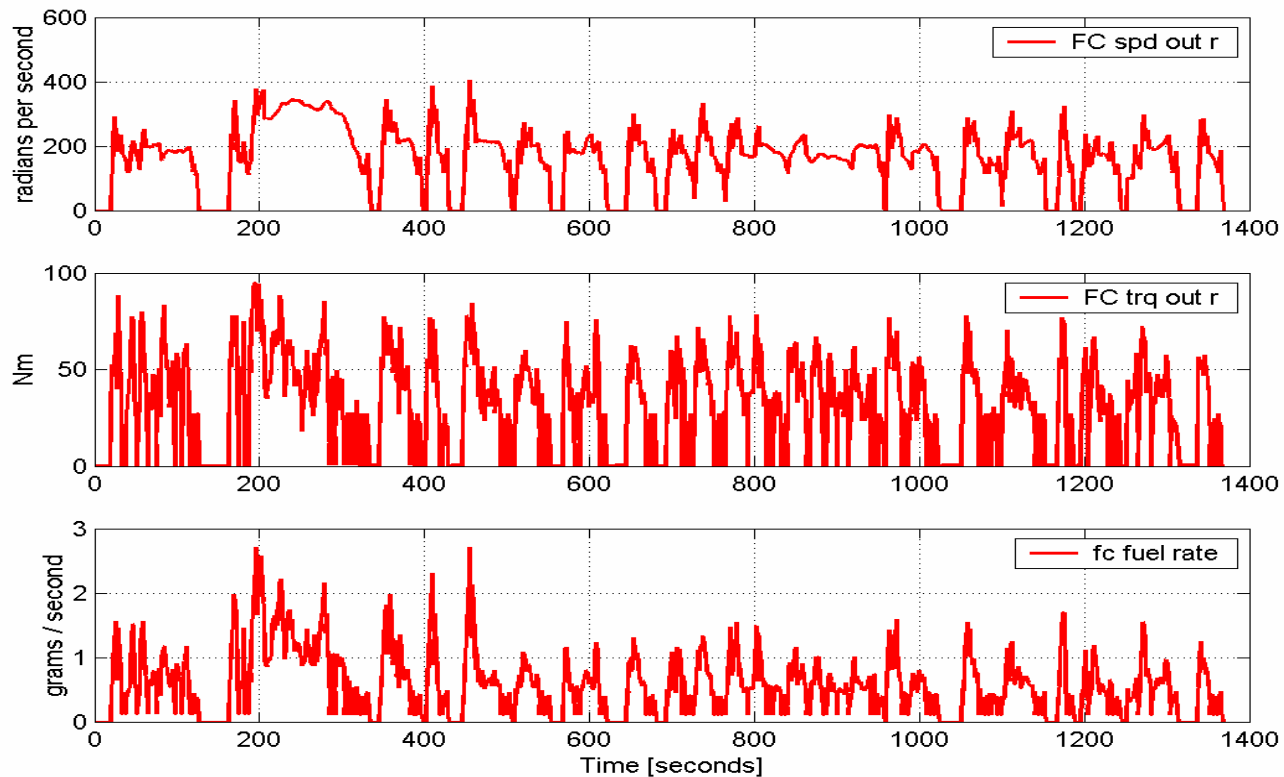
Traces showing the drive cycle and the SOC for the batteries



Hybrid Battery Sizing Sample Study

Baseline Vehicle Results

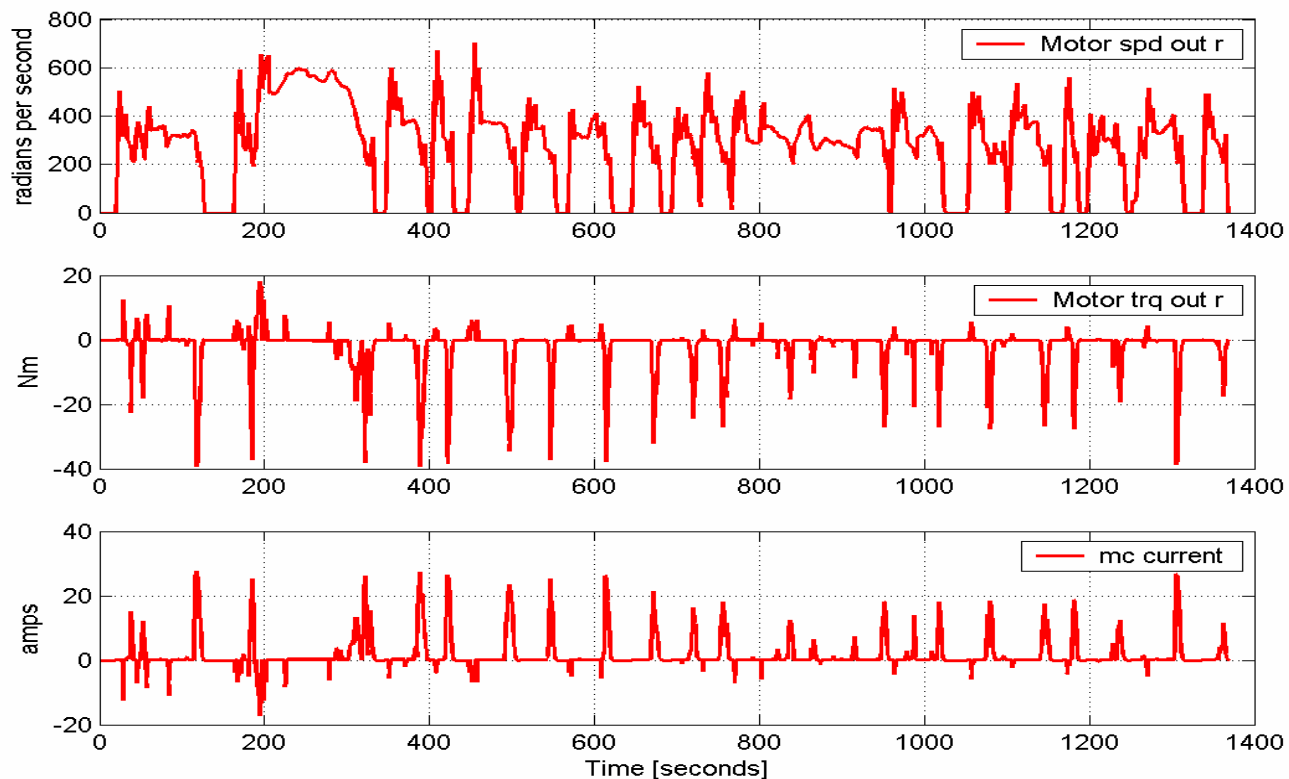
Traces showing the engine activity



Hybrid Battery Sizing Sample Study

Baseline Vehicle Results

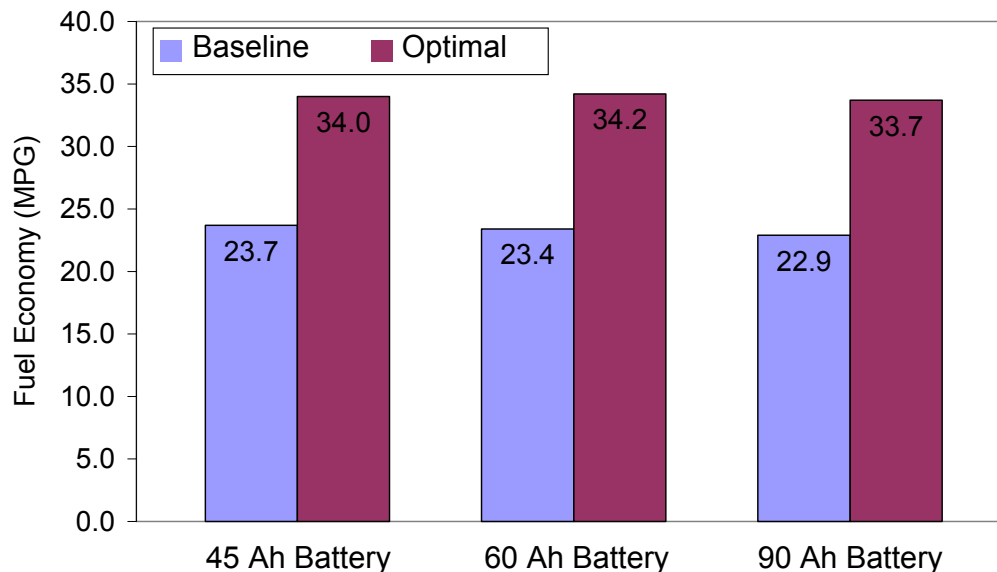
Traces showing the motor / generator activity



Hybrid Battery Sizing Sample Study Optimization Results

- **Optimization**
 - **Robust: Over 450 co-simulation runs**
 - **Automated**
 - **Integrated: Same optimization setup as running without co-simulation (all Saber values are passed from ADVISOR)**

Fuel Economy Improvements from Optimization



Battery Type		Engine Size (kW)	Motor Size (kW)
45 Ah	Baseline	39	56
	Optimal	34	32
60 Ah	Baseline	39	56
	Optimal	32	36
90 Ah	Baseline	39	56
	Optimal	34	36

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Conclusions

- **ADVISOR can now simulate a more detailed parallel electric hybrid by co-simulating with Saber**
- **Electrical component suppliers can now evaluate their Saber models in a full parallel hybrid vehicle context**
- **The co-simulation is completely integrated**
 - **Saber values are automatically sent in from ADVISOR**
 - **Automatically runs from the ADVISOR graphical user interface**
- **The co-simulation is robust**
 - **Capable of automated optimization routines**